# Adriatic Circulation Studies

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## LONG-TERM GOALS

To contribute to the understanding of the dynamics of marginal seas such as the Adriatic by collecting and interpreting observations of currents and water mass properties (e.g., temperature, salinity, chlorophyll concentration). In particular, to study the variability of the surface velocity and temperature/chlorophyll fields in the Adriatic at the meso-, seasonal and interannual scales and to assess the impact of the wind forcing and fresh water runoffs.

## OBJECTIVES

1) To study the variability and structure of the entire Adriatic Sea circulation by producing accurate seasonal maps of mean surface currents and eddy variability using a comprehensive drifter data set covering the period 1990-1999. To estimate Lagrangian statistics, such as single particle diffusivity, Lagrangian time and space scales.

2) To use the comprehensive drifter database, along with satellite images, to describe the spatial characteristics and the temporal evolution of the surface circulation, the sea surface temperature (SST) and the surface chlorophyll concentration in the Adriatic Sea, from meso- to interannual scales. To investigate some aspects of the response of the surface circulation and SST/chlorophyll to atmospheric (e.g., winds) and boundary (e.g., river runoffs) forcings.

## APPROACH

1) The analysis and interpretation of historical Adriatic surface drifter data sets collected between 1990 and 1999 by various organizations, mostly by the SACLANT Undersea Research Centre (SACLANTCEN), by the Naval Oceanographic Office (NAVOCEANO) and by the Naval Postgraduate School (NPS). Eulerian and Lagrangian statistics of the Adriatic surface circulation and SST are computed. Sampling random and bias errors on the mean flow estimates are estimated.

2) The use of satellite images concurrently with the drifter data to describe the variability of the surface currents, SST and surface chlorophyll fields in the Adriatic Sea. AVHRR images archived by SACLANTCEN and processed by the Satellite Oceanography Laboratory of the University of Hawaii (Dr. P. Flament) are used to study the SST variability during periods of large drifter concentration, i.e., 1995, 1997 and 1998. SeaWiFS images downloaded from the Goddard DAAC and processed at the Tiburon Remote Sensing Laboratory of San Francisco State University (Dr. N. Garfield) are utilized to create maps of surface chlorophyll concentration for fall 1997 and the entire year 1998.

## WORK COMPLETED

1) The data from about 200 Adriatic surface drifters between 1990 and 1999 were acquired from various institutions (mostly NPS, SACLANTCEN and NAVOCEANO). The data were quality controlled, reduced, edited for obvious outliers and processed to create low-pass filtered time series sampled uniformly at 6-hour intervals. Technical details about the drifter systems and the drifter data processing, along with graphical representations of the data, have been assembled in a dedicated world wide web page (NPS, 2000) and on a CD-ROM that will be available at the end of the year.

Eulerian and Lagrangian statistics were estimated from the Adriatic drifter data (Poulain, 2000). These statistics include: Eulerian maps of mean flow, velocity variance, mean and eddy kinetic energy, divergence and vorticity; seasonal maps of mean flow and velocity variance; estimates of diffusivity, Lagrangian space and time scales, etc. In addition, random and bias (e.g., the "array" bias) sampling errors on the mean flow estimates were assessed.

2) More than 1000 AVHRR images of the Adriatic were processed for the period Jan.-Dec. 1998. The processing included registration, navigation, calculation of SST and cloud masking.

Over 200 SeaWiFS images were processed using the SeaDAS software to produce color-coded chlorophyll maps of the Adriatic Sea for fall 1997 and and the entire year 1998 (Mauri and Poulain, 2000).

3) Related work: (1) Eulerian and Lagrangian circulation statistics were also estimated from surface drifter data for other basins of the Mediterranean, including the Algerian Current area, the Ionian and Levantine Seas (Mauerhan, 2000). (2) I have contributed to four chapters of an upcoming book on the physical oceanography of the Adriatic Sea (Cushman-Roisin, Gacic, Poulain and Artegiani, Eds.).

## RESULTS

1) Maps of mean currents, subtidal velocity variance, and mean and eddy kinetic energies were produced using a 40-km averaging scale. The mean flow map confirms the global cyclonic circulation in most of the Adriatic basin, broken into three re-circulation cells in the northern, central and southern sub-basins, the latter two being controlled by the bathymetry of the Jabuka and South Adriatic Pits, respectively. An isolated cyclonic gyre prevails near the head of the basin. Mean subtidal velocities in the cyclonic gyres are rather high and can exceed 25 cm $s^{-1}$ in the coastal areas. Velocity variance is maximum (reaching 300 $cm^2$ $s^{-2}$) in the coastal currents. It is essentially due to either mesoscale instability features or fluctuations, even reversals, of the prevailing flows following synoptic wind events.

Values near $2 \times 10^7$ $cm^2$ $s^{-1}$, 2 days and 18 km were obtained for the diffusivity and the Lagrangian integral time and spatial scales in the along-basin direction, respectively (Fig. 1). In the across-basin direction, the statistics are typically 50% of the above values. Geographical and seasonal variations of the Lagrangian statistics can be substantial. It was found that the fluctuating velocities (or the mesoscale eddies) have a preferential cyclonic sense of rotation.

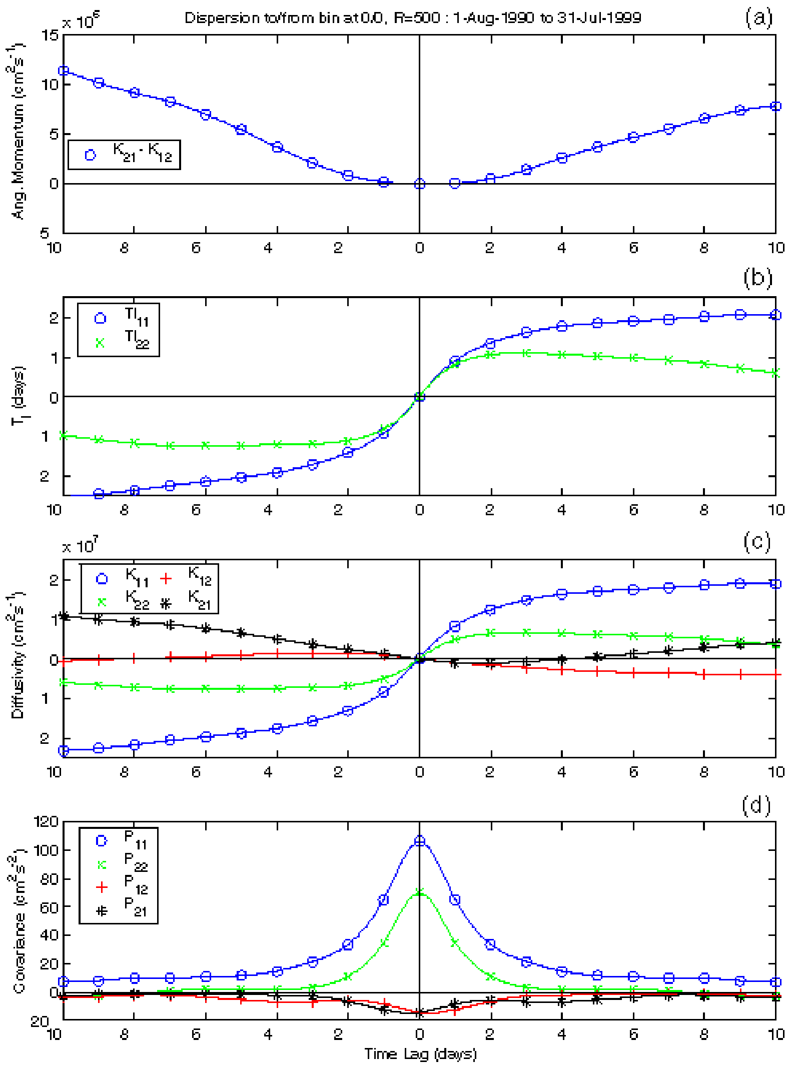


***Fig. 1. Lagrangian statistics calculated for the entire Adriatic basin after removal of the mean Eulerian circulation. All statistics are shown versus time lag between –10 and 10 days. (a) Mean angular momentum; (b) Lagrangian integral time scale; (c) Diffusivity and (d) Lagrangian velocity covariance (see notation in Poulain, 2000).***

The seasonality of the Eulerian statistics were explored, mostly in the central and southern sub-basins. The gyres and the coastal currents are prevailing in summer/fall. In winter/spring they are less intense but the southern one tends to re-circulate more around the South Adriatic Pit. Eddy kinetic energy is maximum in summer/fall.

The drifters showed that the Western Adriatic Current has a width varying between 45 and 70 km. In the northern and central sub-basins, maximum velocities are found within 5-10 km off the coast in winter and spring, while a weaker maximum is seen more offshore (15-25 km) during the other seasons. In the southern Adriatic, the current is weaker and wider in summer, fall and winter, whereas in spring it becomes thinner and swifter (maximum core speed near 10 km from shore and width of about 50 km).

2) Drifter, SST and chlorophyll observations in the northern Adriatic during the period September-October 1997 revealed very complex mesoscale dynamics, with time scales of a day or two and length scales of about 10 km, including the meandering and instability of basin-scale currents (e.g., the western coastal layer), jets/filaments and eddies (Fig. 2). In addition, the two typical patterns of the Po River plume were observed and qualitatively explained in terms of wind forcing. A basin-wide double gyre pattern spreads the rich runoff water across most of the northern Adriatic from mid-September to early October, following Bora wind events and under stratified sea conditions. In contrast, in late October the Po plume is confined to the coast due to weaker winds and de-stratified conditions.

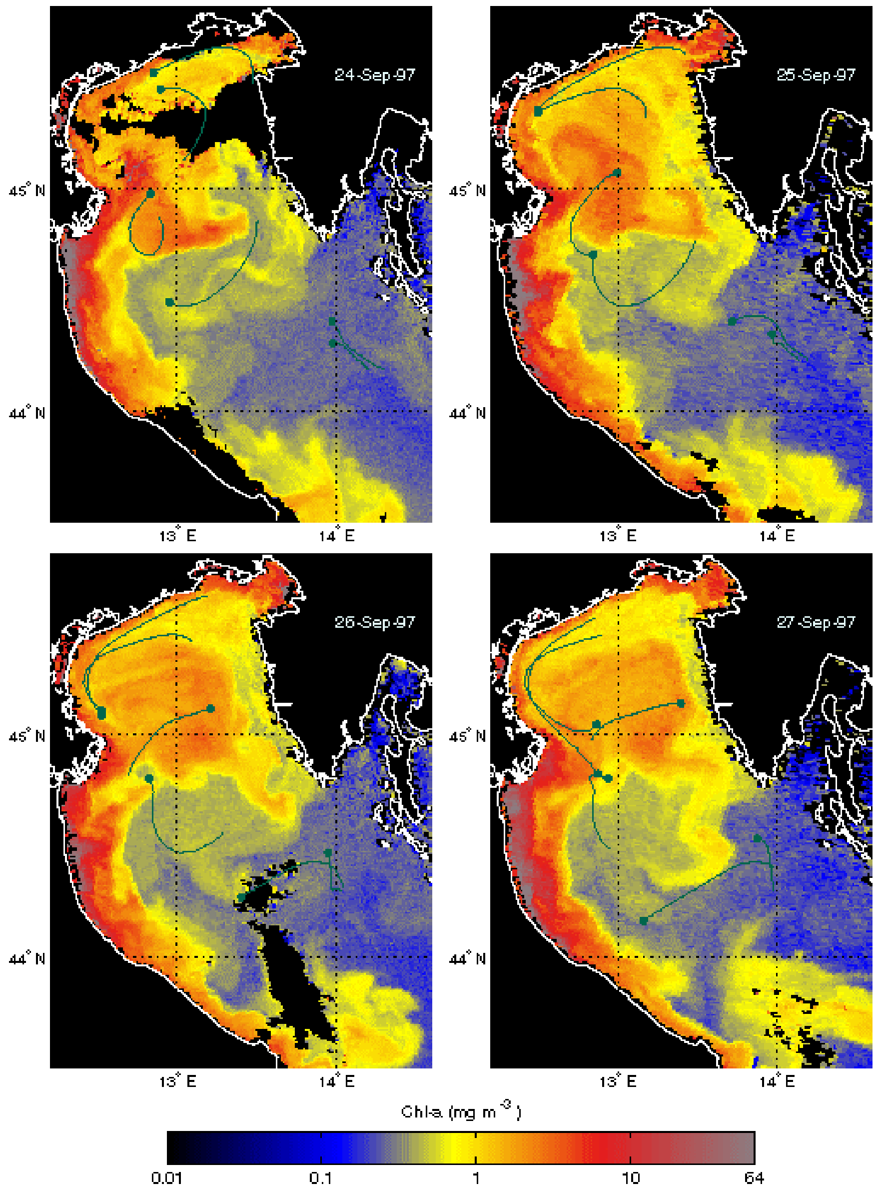


***Fig. 2. SeaWiFS color-code images of surface chlorophyll-a concentration for 24, 25, 26 and 27 September 1997. Drifter trajectories are superimposed in green for a period of 3 days preceding the satellite pass. The "worm head" represents the drifter location at the time of the image.***

## IMPACT/APPLICATION

The scientific impact of this project will be to increase our understanding of the Adriatic Sea dynamics and of the major forcing mechanisms. Future application could be the assimilation of the drifter data into numerical models in the framework of the anticipated Mediterranean Forecasting System (MFSPP, 2000). The knowledge gained from the drifter data will be very helpful for the planning of a new international field program in the northern Adriatic scheduled for 2002-2003 (ACE, mostly organized by NRL and SACLANTCEN).

## TRANSITIONS

Graphical representations of the drifter data were made available on the world wide web (NPS, 2000) in quasi-real time and could be used by anyone interested in the Adriatic surface currents and temperature (e.g., for rescue, military and fisheries operations). The drifter SST data were also directly distributed onto the Global Telecommunication System (GTS) in order to be assimilated into models for weather forecasting.

This program proves the usefulness of the drifters that NAVOCEANO has been (and is currently) using to obtain environmental observations during sea operations, to quantitatively estimate surface currents.

It is planned to assimilate the drifter data (velocities and SST) into various numerical models of the circulation in the Adriatic to improve forecasting skills (Horton et al., 1997; Cushman-Roisin and Naimie, 2000; MFSPP, 2000; and COAMPS).

## RELATED PROJECTS

**Other ONR Projects:** Drs. B. Cushman-Roisin and C. Naimie (Dartmouth College) have been funded to develop a comprehensive, finite-element model of the Adriatic Sea. Comparison studies between model results and the drifter data are in progress. Drs. A. Griffa , T. Ozgokmen and A. Mariano (RSMAS, University of Miami) and I have been funded to develop new methodologies to use Lagrangian data to enhance mesoscale prediction skills. Applications have been performed using the Adriatic drifter data.

**European Projects**: Observations (e.g., XBTs, hydrographic surveys) and modeling efforts of the Mediterranean Forcasting System Pilot Project (MFSPP, 2000) will be compared to our Adriatic drifter dataset.

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